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The toxicity of suspended sediments on selected freshwater invertebrates[1]

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With 3 figures and 6 tables in the text

Introduction

Understanding the effects of either man-made or natural disturbances on aquatic ecosystems is necessary to determine how ecosystems are altered by disruptions. Such an understanding of disruptive processes also is useful in designing water quality and ecosystem improvements. Toxicity testings are useful for determining the effects of specific pollutants on aquatic organisms. Single and multiple species tests for median lethal concentrations (LC_{50}) or median effective concentration (EC_{50}) are a part of state-of-the-art techniques for determining potential impact of new chemicals in premanufacture testing (USEPA 1979). The concept of toxicity tests also can be utilized for other purposes, such as water quality monitoring or testing (MACIOROWSKI & CLARKE 1980). Several recent publications (CAIRNS 1983, LEVIN & KIMBALL 1984, ODUM 1984) have pointed to the need for more realistic ecosystems-level testing rather than single species laboratory bioassays.

During ecological evaluations, questions commonly arise concerning the tolerance of specific organisms to stressors or the ability of organisms to indicate stress in an ecosystem characterized by specific problems. Such a case occurred during a study of the environmental condition of Bear Creek, an 80-km long flatland delta stream system in the Mississippi River alluvial delta (COOPER & BURRIS 1984). Four species of bryozoans were indigenous to three lakes in the system having the lowest total solids, sedimentation rates and pH. Absence of *Pectinatella magnifica* in downstream areas correlated with increased total solids and degradation of habitat. While several studies have dealt with the effects of large-scale disruptive processes such as road construction or channelization on aquatic organisms (MATHERS 1978, FARNWORTH et al. 1979, LENAT et al. 1981), few investigations have studied the effects of suspended sediments at concentration levels that are routinely encountered in large agricultural watersheds. Although selective distributions of sessile invertebrates indicated that they could be used to estimate general environmental quality in Bear Creek, specifics of their pollution tolerance could not be ascertained because of variability in the natural ecosystem. Thus, additional controlled experiments were designed to estimate the toxicity of suspended sediments on three species of sessile macroinvertebrates which commonly occur in aquatic ecosystems.

Materials and methods

Two of the species of invertebrates, the sponge *Trochospongilla horrida* and the bryozoan *Pectinatella magnifica*, were collected from Sardis Reservoir in north Mississippi where they typically colonize submerged woody vegetation. Submerged branches with colonies of 100 to 300 organisms were severed and placed in a large transport tank filled with lake water. Limbs were positioned and fixed into place in wire cages to prevent physical damage to organisms during transport. At the experimental site (University of Mississippi Biological Field Station) colonies were suspended at 0.5 m depth in a 0.5 ha holding pond (SP-2), where the temperature approximated that of Sardis Reservoir (27 °C), for a one week acclimation period. The third species, the bryozoan *Plumatella repens*, was abundant in the holding pond and readily colonized (20 to 100 zooids per colony) $0.3\,m^{-2}$ glass plates placed at 0.5 m depth.

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The suspended sediment dilution water used in all experiments was transported from a small pond (< 0.5 ha) in nearby Panola County, MS. The pond chosen as a suspended sediment source was typical of gravel pit ponds in the area and was especially useful because its water contained colloidal clay (3900 to 5000 mg/l) that remained in suspension indefinitely. Physically mixing clay into suspension on site was undesirable because high concentrations of suspended materials resembling storm runoff would not remain in suspension for more than 24 hours. A scan for current use and residual insecticides, herbicides and heavy metals by the Soil-Plant Analysis Laboratory at Northeast Louisiana University, Monroe, Louisiana, revealed all sediment pond and holding pond water to be free of contaminants such as pesticides and metals that might adversely affect the experiments. After tank water temperature equalized with holding pond water, healthy test colonies were transferred to test tanks and suspended from wire frames. Labelled colonies were counted and conditions noted every 24 hours for 96 hours. Death in the two species of bryozoans was defined as no response to stimuli, i.e. tentacles of individual zooids showed no reflex response when teased with a needle-point probe. Death in sponges was defined by tissue discoloration and gemmulation. Preliminary experiments showed these conditions were not reversible.

Three sets of experiments in August and September, 1983, involved subjecting the test organisms to different concentrations of suspended sediments. Each test was a refinement of the one that preceded it. In experiment 83-1, three 4000 l tanks were partially submerged in a second pond (0.02 ha) which filled directly from the main spring-fed holding pond. Water was continuously circulated through the pond to regulate the water temperature in the tanks so it did not become a limiting factor. Tank 1, a control, was filled with water from the holding pond. Additional specimens were left in the holding pond (SP-2) as a second control. Tank 2 was mixed (50:50, v/v) with holding pond water and sediment laden water from Panola County, while Tank 3 was filled with sediment laden water (3900 mg/l). Table 1 summarizes the tank mixtures. Experiment 83-1 was a static experiment, i.e. no renewal or flushing occurred after the experiment began.

The second set of experiments (83-2) utilized 40 l aquaria, also mainly submerged for temperature control, in a more standardized acute toxicity test. Duplicate sets of aquaria were set up for seven dilutions of suspended sediments, ranging from 0 % (control) to 100 % (5017 mg/l) and analysed for 96 hours. These tests were designed to be static with renewal to better approximate natural conditions. One-half of each aquarium volume was exchanged each day of the experiment with a pre-mixed proper dilution so that metabolic wastes were flushed out but sediment concentration did not change. Results from experiment 83-2 showed that more dilute concentrations of sediment were needed to properly test the 2 bryozoans. The third experiment (83-3) utilized the static with renewal design and 40 l aquaria from experiment 83-2 but reduced to one-fifth the concentrations of suspended sediments (100 % = 1000 mg/l).

All tests were conducted using dilutions of SP-2 and Panola County pond water under natural solar radiation and food conditions to reflect, as realistically as possible, ecological conditions found during sediment stress on the three species of invertebrates. Temperature, conductivity, dissolved oxygen and pH were measured with a commercially available water quality monitor which was calibrated daily. Nitrate nitrogen, ammonia nitrogen, ortho- and total phosphorus (USEPA 1975), total and dissolved solids and chlorophyll analysis (spectrophotometic) (APHA 1975) followed standard methods.

Table 1. Tank mixtures for experiment 83-1.

Location	Volume (l)	Source of water	Sediment (mg/l)
SP-2 (Control)	1.1×10^5	Holding pond (SP-2)	11
Tank-1 (Control)	4000	Holding pond (SP-2)	11
Tank-2	4000	SP-2 — 50 %	
		Sediment pond 50 %*	2072
Tank-3	4000	Sediment pond 100 %*	3914

* From Panola County, MS, USA.

Results and discussion

A summary of physical data for experiment 83-1 (Table 2) showed that values in the three experimental tanks were not significantly different ($P < 0.01$) from the holding pond (SP-2) except for suspended sediments. Values for initial and final concentrations of phosphorus and nitrogen are listed in Table 3. All parameters were within the range normally experienced during the summer in the southern region of the United States.

All three species examined in experiment 83-1, the preliminary 4000 l tank experiment, responded to increased suspended sediments with high rates of mortality (Table 4). *Trochospongilla horrida* had 100% mortality in tanks 2 and 3. *Plumatella repens* had higher 96 hour mortality rates at the 50 : 50 concentration of suspended material rather than at the high concentration. The third species, *Pectinatella magnifica*, showed high mortality in all three tanks. Colonies of *P. magnifica* were adversely affected by extensive daily handling, a detrimental algal bloom within the colonies gelatinous matrix produced under static conditions, and the high concentrations of pollutant (Table 4). Knowledge of these factors resulted in the alteration to static with renewal design for experiments 83-2 and 83-3.

A summary of the physical data for experiment 83-2 (Table 5) indicated that increasing suspended solids corresponded to slight declines in conductivity, dissolved oxygen and pH. There was little variation from initial chemical concentrations (Table 6) during experiment 83-2. Chemical and physical parameters in 83-3 were not significantly different from those in 83-2. 48 and 96 hour mortality rates for *Trochospongilla horrida* in exp. 83-2 (Fig. 1) responded predictably to increasing sediment concentrations. The 48-hr LC_{50} was calculated as 1490 mg/l or 29.7 % of the maximum suspended sediment concen-

Table 2. Physical data (means) for water used in experiment 83-1.

Location	Temperature °C	Conductivity μmhos/cm^{-1}	Dissolved oxygen mg/l	pH	Suspended sediments mg/l
SP-2	27.8	20.6	9.6	6.2	5
Tank-1	27.5	20.6	9.8	6.1	11
Tank-2	27.2	21.0	9.7	6.1	2100
Tank-3	27.2	20.9	9.7	6.0	3900

Table 3. Initial and 96 hour chemical concentrations for experiment 83-1.

Tanks (hour)	Phosphorus filtered ortho mg/l	Phosphorus non-filtered ortho mg/l	Phosphorus non-filtered total mg/l	NO_3-N mg/l	NH_3-N mg/l
SP-2 (0 hour)	0.008	0.008	0.018	0.032	0.143
(96 hour)	0.007	0.008	0.017	0.030	0.141
1 (0 hour)	0.005	0.006	0.020	0.022	0.153
(96 hour)	0.009	0.009	0.019	0.031	0.056
2 (0 hour)	0.008	0.017	0.099	0.019	0.045
(96 hour)	0.011	0.011	0.043	0.043	0.088
3 (0 hour)	0.009	0.017	0.154	0.015	0.987
(96 hour)	0.009	0.031	0.185	0.025	0.027

Table 4. Mortality of three species of invertebrates exposed for 96 hr to simulated storm flow-suspended sediments in experiment 83-1.

Location	Replicate	*P. repens* mortality (%)	*T. horrida* mortality (%)	*P. magnifica* mortality (%)
SP-2	1	0	1	5
	2	0	0	0
	3	3	2	2
	4	0	0	1
Tank-1	1	0	10	25
	2	2	0	70
	3	0	0	55
	4	0	0	75
Tank-2	1	100	100	75
	2	90	100	100
	3	100	100	65
	4	100	100	90
Tank-3	1	90	100	100
	2	60	100	100
	3	90	100	90
	4	100	100	100

Table 5. Physical data (means) for water used in experiment 83-2.

Aquarium #	Temperature °C	Conductivity μmhos/cm^{-1}	Dissolved oxygen mg/l	pH units	Suspended sediments mg/l
1A	29.4	33.4	8.1	7.7	5
1B	29.5	33.0	8.0	7.7	16
2A	29.6	33.0	6.7	7.5	505
2B	29.8	32.0	7.3	7.4	442
3A	29.7	31.0	6.8	7.3	890
3B	29.8	31.0	7.0	7.3	886
4A	29.5	30.0	7.0	7.1	1232
4B	29.6	29.0	6.9	7.0	1240
5A	29.7	28.0	6.5	7.0	1567
5B	29.6	28.0	6.3	6.9	1513
6A	29.6	27.0	6.8	6.9	2730
6B	29.6	26.6	6.8	7.1	2661
7A	29.6	27.0	7.4	7.3	4993
7B	29.5	27.6	7.2	6.8	5017

tration. The 96-hr LC_{50} was 600 mg/l (11.9 %). Colonies of *Plumatella repens* responded adversely to the high concentrations of sediments in 83-2. Except for controls, all colonies showed 80—100 % mortality.

Mortality rates for *Pectinatella magnifica* in experiment 83-2 revealed a complex reaction (Fig. 2) of the bryozoans to increasing concentrations of suspended sediments. Mortality at 48 hours increased with increasing suspended sediment concentration to approximately 900 mg/l (18 %). At the next highest dilution, 25 % or 1100 mg/l, mortality rates declined sharply to a mean value of only 9 % of the zooids. At 32 %, or 1600 mg/l, mortality rates were only 19 %. These results were substantiated in 3 separate colonies in each of duplicate aquaria. Colony size varied from 100 to 300 zooids. Daily observations

Table 6. Initial concentrations of P and N (0 hour) in water for experiment 83-2.

Aquarium #	Phosphorus filtered ortho mg/l	Phosphorus non-filtered ortho mg/l	Phosphorus non-filtered total mg/l	NO_3-N mg/l	NH_3-N mg/l
1A	0.017	0.018	0.047	0.040	0.092
1B	0.020	0.020	0.050	0.040	0.172
2A	0.003	0.003	0.020	0.039	0.048
2B	0.003	0.003	0.015	0.036	0.121
3A	0.003	0.003	0.014	0.025	0.141
3B	0.003	0.003	0.014	0.023	0.201
4A	0.003	0.003	0.026	0.022	0.064
4B	0.003	0.005	0.020	0.033	0.028
5A	0.003	0.003	0.026	0.030	0.029
5B	0.005	0.005	0.026	0.029	0.025
6A	0.008	0.012	0.119	0.050	0.132
6B	0.009	0.014	0.096	0.058	0.030
7A	0.021	0.099	0.516	0.070	0.040
7B	0.012	0.079	0.489	0.147	0.118

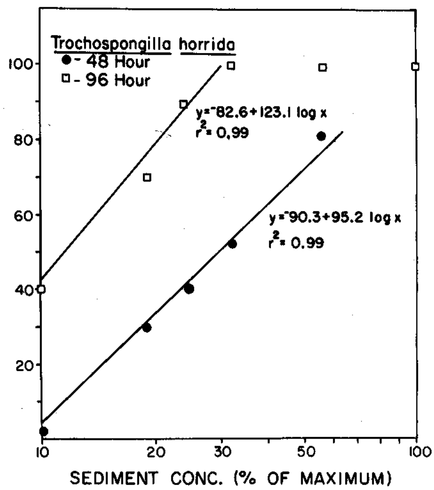

Fig. 1. Experiment 83-2 concentration-mortality plots for the poriferan, *Trochospongilla horrida* for 48 and 96 hours exposure to suspended sediments (100% = 5017 mg/l).

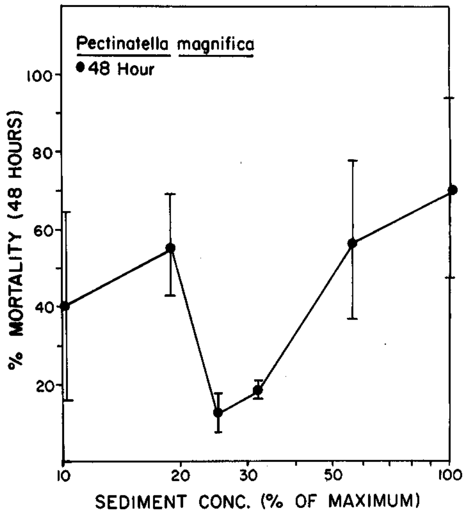

Fig. 2. Experiment 83-2 concentration-mortality plot for the bryozoan, *Pectinatella magnifica* for 48 hour exposure to suspended sediments (range indicated by vertical bars).

of zooids provided one possible explanation. Zooids at lower concentrations of suspended materials attempted to continue active feeding and, thus, were quickly choked by ingested sediments. Zooids placed in higher concentrations reacted by immediate retraction of tentacles and suspension of feeding activities. This survival mechanism temporarily enabled them to avoid fouling by sediments. By 96-hours, most colonies were dying but 96 hour results showed wide variations which seemed colony specific and were not predictable.

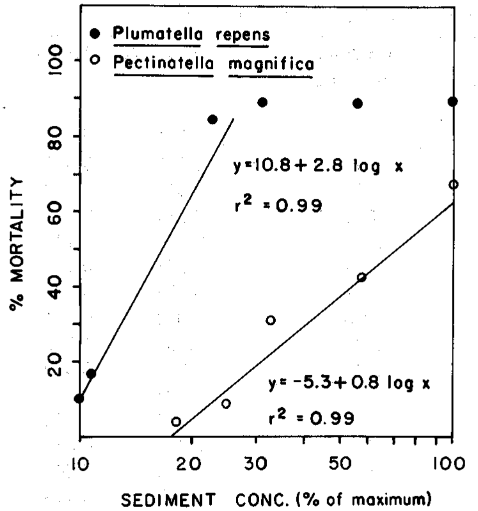

Fig. 3. Experiment 83-3 concentration-mortality plot for the bryozoans *Plumatella repens* and *Pectinatella magnifica* for 96 hour exposure to suspended sediment (100% = 1000 mg/l).

Experiment 83-3 was a repeat of 83-2 except that the maximum sediment concentration was 1000 mg/l instead of 5000 mg/l. The lower concentrations allowed for greatly improved curve-fitting and both *Plumatella repens* and *Pectinatella magnifica* responded predictably. *Plumatella repens* was the most sensitive to suspended sediments of the three species tested. The 96-hr LC_{50} was calculated to be 160 mg/l (Fig. 3). Mortality rates leveled at 85 to 90% of the population when suspended sediment concentration increased above 225 mg/l. These results agreed with those of experiment 83-2.

Pectinatella magnifica responded predictably ($r^2 = 0.99$) with the lower concentrations in experiment 82-3. LC_{50} in experiment 83-2 (100% toxicant = 5000 mg/l) was calculated to be 750 mg/l. In 83-3 (100% toxicant = 1000 mg/l) LC_{50} was 700 mg/l. It should also be noted that handling difficulties experienced with these sensitive organisms in the preliminary experiment were overcome and all three species maintained viable control colonies and experienced colony growth in control tanks. *Pectinatella magnifica* continued sustained colony growth with no mortality during experiment 83-3 in the control and 10% (100 mg/l) tanks.

Adverse conditions commonly imposed on aquatic ecosystems may result from pulses of suspended materials which move through watershed streams following single large runoff events. Suspended sediment concentrations may rise to levels as high as 30,000 mg/l (Long & Bowie 1963) but are quickly diluted. The protective reaction that allowed *Plumatella repens* (83-1) and *Pectinatella magnifica* (83-2) to survive intermediate doses of sediments more successfully than lower doses for short periods in the experiments may allow these invertebrates to survive stormflow where a pulse of suspended material rather than prolonged concentrations presents a problem. Additional research on the effects of sediment pulses on invertebrates and survival mechanisms will be helpful in documenting how aquatic organisms withstand these disruptions.

In summary, three species of invertebrates, *Plumatella repens*, *Pectinatella magnifica*, and *Trochospongilla horrida*, showed high rates of mortality when subjected to high concentrations of suspended sediments, conditions which may exist during sustained rainfall-runoff from agriculture, mining, or construction. Colonies of *Plumatella repens*, which are not affected by low levels of pesticides or sewage (BUSHNELL 1974), had 80 to 100% mortality when subjected to levels of suspended sediments in excess of 200 mg/l for 96 hours. Sponges (*Trochospongilla horrida*) had a 48-hr LC_{50} of 1490 mg/l and were quite predictable in their response to suspended sediments ($P < 0.01$). The predictability with which sponges responded to suspended sediment levels was surprising in light of a collection record of *Trochospongilla horrida* in water with 5300 mg/l ppm turbidity (CHEATUM & HARRIS 1953). Zooids of the bryozoan, *Pectinatella magnifica*, had a 96-hr LC_{50} of 700 to 750 in two separate experiments but their behavior beyond that point was not predictable.

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